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CONTACT-FREE THREE-PHASE LINE VOLTAGE STABILIZER FOR A THREE-WIRE POWER NETWORK

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The principles of constructing resource- and energy-saving power systems based on transformer-thyristor modules are considered taking the example of a contact-free three-phase line voltage 0.4 kV stabilizer for a three-wire power network.

One of the most important problems in supplying electricity at industrial enterprises, including glass factories, is maintaining voltage in the power network at a level not beyond certain admissible limits. This mainly concerns drops (short-term decrease) in voltage or long-term deviations which may be caused by failures in power networks or by the relative position of the power source and the electricity receiver, or by the quality of electric power lines. In certain cases under substantial voltage deviations from the rated value, the normal course of technological process such as bending, electric melting, or annealing of glass can be disturbed.

Most technological lines at industrial enterprises have electric drives equipped with asynchronous motors that are powerful three-phase symmetric consumers. Such consumers are especially sensitive to voltage deviations in power networks, especially when the deviation is uneven in different phases. For instance, the resistance of the negative phase sequence of an asynchronous motor is approximately 5 times lower than that of the positive phase sequence. Therefore, even a slight voltage asymmetry causes substantial negative-sequence currents, which leads to the additional heating of the stator and the rotor. This leads to premature wear of the insulation and a decrease in the available motor power.

A decreased voltage also has a negative effect on motor parameters. Thus, the maximum torque generated by an asynchronous motor is proportional to the voltage on the stator winding, i.e., as voltage drops by 15% from the rated value, the maximum torque of the motor decreases by 25%. Furthermore, as voltage decreases, the motor slip (the difference between the rotational speed of the rotor and the magnetic field of the stator) increases. This raises the strength of the current in the rotor, which increases its wear due to heating, If a motor constantly operates with a 10% voltage decrease, its service life decreases approximately by half. When the voltage increases by 1%, the reactive power consumed by the motor grows by 3 – 7% (i.e., the power factor decreases).

The Stromizmeritel’ JSC together with the Nizhny Novgorod State Technical University researches the development and implementation of resource- and energy-saving power systems for supplying electricity to various receivers based on transformer-thyristor modules (TTM) [1]. TTM are included in power systems (often together with a supplying transformer) in cases where the receivers of electricity have to fulfill the following functions:

– voltage stabilization on input terminals of a group of receivers or critical individual receivers; in doing so, to provide for electromagnetic compatibility with the power network, the stabilizer should not generate higher harmonic current or voltage components;

– voltage regulation on input terminals of a group of receivers or single powerful receivers; this is especially important in wide-range low-step regulation and in the case of inadvisability of using mechanical contacts in the power network;

– compensation of reactive power consumed by a group of receivers or a single powerful receiver directly on input terminals; application of TTM together with a capacitor bank with non-adjustable capacity is obviously preferable for compensating reactive power to the traditional method of sectioning the capacitor bank;

– symmetrizing of currents consumed by an asymmetric load, uniformly for all phases of the network; application of TTM for this purpose makes it possible to exclude traditional

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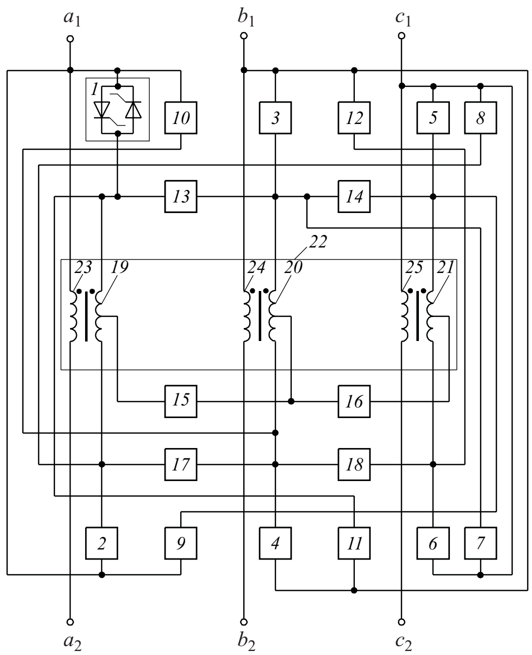

Fig. 1. Functional diagram of TTM.

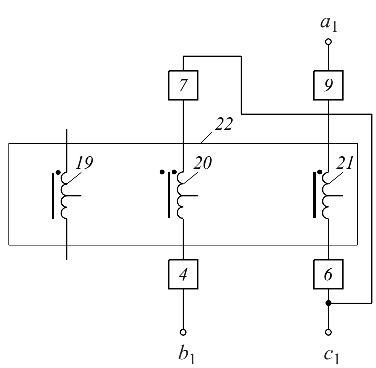

Fig. 2. Diagram of connections of primary transformer windings for regime No. 54.

symmetrizing reactors; the latter have low robustness, which leads to high losses of electricity on their heating, furthermore, they consume reactive power that has to be compensated by increasing the power of the capacitor bank.

The effect of using TTM sharply grows if the network is required to fulfill not one of the above functions, but several of them. By combining several functions on the basis of a single TTM supplying electricity to a group of receivers under optimum control, one can obtain a resource- and energy-saving power system.

Figure 1 shows a simplified functional scheme of a TTM. Thyristor keys (TK) *1 – 18* are intended for various types of connection of primary windings *19 – 21* in transformer *22*, as a consequence of which voltage additives of different values and phases are formed on secondary windings *23 – 25*. The principal scheme of a TK variant is shown in Fig. 1 taking TK *1* as an example.

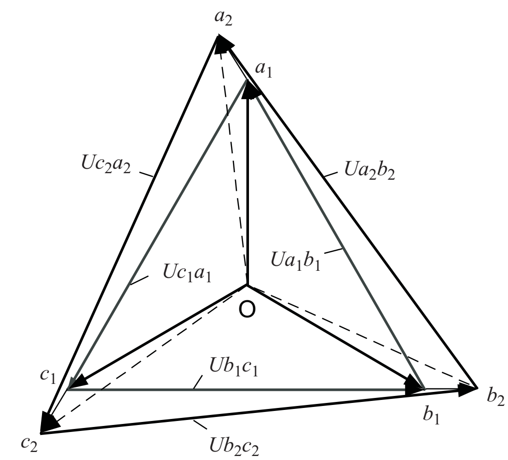

Fig. 3. Vector diagram of input and output TTM voltage for regime No. 54.

The device functions as follows (RF patent No. 2209501). The power network voltage from terminals a_1, b_1, c_1 is transmitted via the TK to the primary winding phases. The phase of voltage applied to the primary winding depends on which TK are turned on in the current operating regime. Depending on this, the voltage on the secondary winding of a variable value and phase is geometrically summed (or subtracted) with the power network voltage. This modifies the voltage of the load connected to terminals a_2, b_2, and c_2. Various combinations of switched on TKs provide for 151 stationary regimes, which differ in the value and phase of voltage on the output terminals.

To illustrate the work principle, Figs. 2 and 3 show the diagram of connections of primary windings *19 – 21* in the TTM transformer *22* (TKs *4*, *6*, *7*, and *9* are turned on) and the corresponding vector diagrams of input voltages Ua_1b_1, Ub_1c_1, Uc_1a_1 and output voltages Ua_2b_2, Ub_2c_2, Uc_2a_2 for one of the stationary operating regimes (regime No. 54 in the registered database). It is clear from the voltage vector diagram that, due to a single magnetic circuit in the transformer, one can perform both scalar and vector operations with voltage vectors used to form volt additives, i.e., it is possible to modify the output voltage phase with respect to the corresponding input phase. This property of the stabilizer makes it possible to correct the asymmetry of the three-phase voltage system.

The use of a TTM with a three-phase transformer for stabilizing and regulating voltages has a positive effect on the weight and size parameters of the device, as compared to using three volt-adding transformers for each separate phase, and allows for interphase power exchange (through the common magnetic circuit), which makes it possible to obtain a large number of steps in regulating output voltages, despite relatively few power elements. The simplicity of the power block of the TTM-based device improves its reliability. Furthermore, such structure of the power block makes it possible to regulate line voltage of the power network, which cannot

be achieved by the majority of stabilizers offered on the market, which are designed for four-wire three-phase networks and which stabilize only phase voltages.

One of the main principles of the TTM design is ensuring magnetic compatibility of the TMM with the power network and load. As a consequence, they should not generate higher harmonic voltage or current components in service. Therefore, in all stationary regimes part of the TKs in the TTM are switched on during the total period of supplying voltage, whereas certain other TKs remain switched off. To convert the TTM from one stationary regime to another, special algorithms with natural switching of TK have been developed. This prevents the formation of extra currents and overvoltages on TTM elements in dynamic operation modes, which provides for electromagnetic compatibility of the module with the network. All algorithms for converting the TTM to various stationary regimes are found in a unified registered database.

Based on the specified method for transforming three-phase voltage using a TTM, the Stromizmeritel' JSC has designed and constructed a prototype contact-free three-phase line voltage stabilizer of 0.4 kV for three-wire power networks. The stabilizer is intended to provide a rated line voltage for a load up to 1 kW with an accuracy of at least ± 1.5% within the voltage variation range in a three-phase network equal to ± 10% of the rated value.

The functional diagram of the stabilizer is shown in Fig. 4. The plant consists of power block *1* constituting a TMM and a control system including current and voltage sensor block *2*, analog-to-digital converter (ADC) block with input-output device *3*, a block generating TK control signals *4*, power block *5*, and processor block *6*.

Block *2* contains sensors of instant line voltage values based on the Hall effect, which are transmitted to the stabilizer input, as well as instant value sensors of load phase currents and TK currents. The signals received from these sensors are the source data for the control program selecting optimum stationary regimes for the stabilizer at a given moment and ensuring the transition from one stationary mode to another with minimum overloads on TK and other elements of the stabilizer.

Block *3* includes the microcircuit of a 12-digit Maxim 191 ADC with the corresponding system for matching analog and digital signals, comparators, and Altera EPM7128BTC100-7 logic programmable matrix used as the input-output block. The ADC is intended for the conversion of analog signals from the sensors into a digital code for subsequent data processing in the microcontroller located in the processor block. The comparators serve for synchronizing the sensor signals with the TK control signals and the phases of measuring and processing signals in the ADC. The programmable logical matrix is used to ensure digital code exchange between the microcontroller and the ADC, as well as between the microcontroller and the block for generating TK control signal.

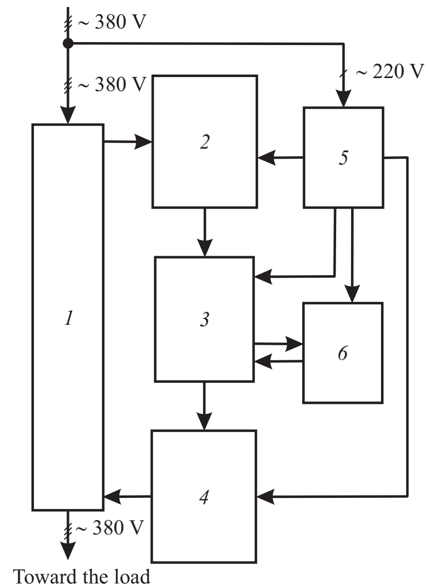

Fig. 4. Functional diagram of voltage stabilizer.

Block *4* is intended for generating and amplifying TK control signals and galvanic decoupling between the control system and the power block.

The power block provides the required voltage to all blocks of the control system.

The processor block is a AT91EB63 microcontroller circuit board including a 32-digit RISC microcontroller ATMEL AT91M63200, operational memory (256 kb), and power-depending Flash memory (2 Mb). The software of the control system consists of the modeling program and the control program operating in real time. The purpose of this separation is to decrease the volume of complex calculations in real time related to searching for an optimal stationary mode for the stabilizer. The modeling program is intended for calculating the list of numbers used in the stationary regimes of the stabilizer for all possible combinations of line voltages in the network in the preset range (340 – 420 V) with a preset variation interval equal to the stabilization accuracy (± 1.5%). Furthermore, an additional restriction is the maximum admissible voltage asymmetry coefficient based on the negative phase sequence (not more than 4% according to GOST 13109–97 standard). The results of the modeling program are encoded and added to the control program code, which uses it as a database.

A prototype of such voltage stabilizer in 1986 was installed at the transformer substation of the glass-bending division at the Borskii Glass Works [2]. The upgraded stabilizer has the following advantages compared with the prototype:

– has a general purpose, i.e., is able to perform in a wide range of load currents (0 – 100%) under various loads without a loss of stabilization accuracy;

– uses stationary operation regimes making it possible not only to stabilize, but also to symmetrize, line voltages;

– programmability of the control system and, consequently, the flexibility of tuning the stabilizer parameters;

– fast operation of the microprocessor control system, due to which the restriction on the size of databases used in calculations and searches for optimum operating regimes and transition algorithms has been lifted;

– application of more perfect voltage and current sensors based on the Hall effect, which have higher precision than the current transformers and a smaller phase shift between the measured current or voltage and the output signal, and which make it possible to register the constant component in the measured parameter, which is useful for identifying emergency regimes of the stabilizer.

The positive results obtained during the development and testing of the stabilizer prototype, as well as the constant interest of customers in developing power networks based on TTM, give reason to hope for an extensive implementation of such devices in various sectors of industry.

REFERENCES

1. I. M. Tumanov, V. I. Popov, and Yu. N. Petrov, *Transformers, Transformer-Thyristor Modules and Power Systems Based on Them* [in Russian], Nizhny Novgorod (2002).
2. I. M. Tumanov, A. K. Kim, A. B. Zhimalov, et al., “Contact-free plant for regulating voltage of electric furnace supply,” *Steklo Keram.*, No. 11, 5 – 7 (1988).